DATE: June 19, 1995

TO: Office Engineers

FROM: S.E. Douglas, P.E., Technical Services Engineer
Division of Wastewater Engineering

THROUGH: Eric H. Bartsch, P.E., Director
Office of Water Programs

C.M. Sawyer, P.E., Director
Division of Wastewater Engineering

SUBJECT: Water & Sewerage - Information - Trenchless Pipe Construction

INTRODUCTION

Several methods are available for new pipe installation without open-cut trenches. New techniques and innovations are being developed at a rapid pace. There are aspects of these trenchless technologies which should be understood by the reviewing engineer. Specifically, the proposed method should be compatible with field conditions and the materials suitable for the installation and service. The method chosen should not compromise the integrity of the pipe, lining or coating system.

OVERVIEW

Trenchless construction methods can be categorized into entry or non-entry methods. Entry methods require workers inside the bore hole for excavation and pipe/liner installation. Tunneling and Pipe Jacking are two entry-type methods. Non-entry techniques are referred to as Horizontal Earth Boring methods and comprise a large variety of mechanical excavation procedures and equipment. Non-entry methods do not require workers inside the bore hole. This classification system follows that recommended by the *Committee on Construction Equipment and Techniques*, ASCE.(1)

Horizontal earth boring methods are common. Several utilities have adopted construction standards, as illustrated in HRSD and Hanover County's standard details, given in Figure 1.

FIG. 1 STANDARD DETAILS

DESCRIPTION OF METHODS

1. <u>Tunneling</u> - Excavation in clay or granular material occurs inside a tunneling shield at the face of the excavation. The shield is a hood beneath which the miners work, and it protects the workers by keeping the bore open. It may be open-face or it may have ports in the face through which material flows. (8) The shield is hydraulically jacked forward during excavation, and the lining is installed in the tail end. Liners are typically steel or precast concrete plates, or steel ribs with wood lagging. The minimum practical size is 48-inch diameter. (1)

Normally the utility pipe is installed inside the tunnel lining. (2) Several techniques have been used to move the pipe into place inside the tunnel - ranging from simple skids or roller systems to specialized machines which position and join the pipe sections. (8)

2. <u>Pipe Jacking</u> - Pipe jacking requires an excavation at both ends of the pipeline. The tail-end pit houses the jacking equipment and support structure. New pipe sections are inserted into the pit (with the jacks retracted) and the sections are joined, then the entire pipe string jacked forward. Excavation methods vary, but usually a shield is used. A bentonite slurry may be used on the outside of the pipe to lubricate it and reduce jacking loads. Intermediate jacking stations and continuous operation are also employed to reduce loads.(1) A typical pipe jacking set-up is depicted in Figure 2.

This method is used for pipes 36-inches diameter and larger. It is limited to straight runs. Both gravity and pressure pipelines can be installed. Spans range from 80 - 3000 ft.(2) Primarily, reinforced concrete pipe is used. However, other pipes may be suitable to pipe jacking, such as steel, ductile iron, Hobas (fiberglass), and corrugated metal pipe. (1)

3. <u>Horizontal Earth Boring</u> - Most of the recent advances in construction have focused on Horizontal Earth Boring systems. Several subcategories exist. These methods are compared in Table 1. They are further described as follows:

A. *Auger Boring*

Auger boring is the most common trenchless construction method in the U.S. (2) A rotating flight auger simultaneously jacks the casing through the earth while transferring the spoil back out. Two classes of rotating flight augers exist: Track-type and Cradle-type.

The excavation pit houses most of the boring equipment in the Track-type method. The pit is manned and it remains open for an extended time. Consequently the foundation structure must be secure and it must be kept dewatered. A typical track-type installation is depicted in Figure 3.

Track-type auger boring involves a cycle of operations. The cutting head and auger are moved to the rear of the track, a casing section is aligned and welded to the previous section. After the equipment components are connected, the cutting head and auger rotate forward. The casing pipe is advanced by extending the hydraulic thrust rams against the thrust blocks in the bore pit. After the entire casing pipe is installed, the auger is retracted and the casing is cleaned. Then the carrier pipe is installed.

The Cradle-type method is often referred to as the Side Boom or Swinging method, because the boring machine and pipe-auger system is suspended by construction equipment. The entire pipeline is first connected together in this technique. A cradle-type set-up is shown in Figure 4.(1)

B. *Slurry Rotary Drilling (Slurry Boring)*

Slurry boring is similar to auger boring, except that a drill bit and tubing are used instead of cutting heads and augers, and a drilling fluid is used. The fluid can be air, water, or bentonite slurry. It is not the same as the water-jetting method, because the fluid is not used to cut or wash out the bore, although it assists in removing spoil.

Bentonite slurry is used in noncohesive, unconsolidated soils. It combines with the cuttings to form an impermeable seal of the boring walls.

The pipe is installed after the boring is completed.

C. *Microtunneling*

Microtunneling is a boring method using laser-guided, remotely-controlled equipment. The system achieves accurate line and grade.

Microtunneling uses a boring machine with cutting head and laser target, followed by the pipe which is hydraulically jacked into place. Two subtypes of microtunneling systems exist: those using a slurry spoil removal process and those having an auger spoil removal design. A slurry-type microtunneling operation is shown in Figure 5.(1)

The annular space around the pipe may be filled with a bentonite/polymer slurry to reduce skin friction. Pipe joining methods depend on type of pipe material.(3)

D. *Horizontal Directional Drilling*

This process is an adaptation from the petroleum industry and is used for long, complex crossings under rivers and railroads. No bore or receiving pits are needed. However, a large set-up area is required. Directional drilling is accomplished in 2 stages: first, a small-diameter pilot hole is drilled, second, the pilot hole is enlarged with reamers and the pipe pulled into place. The drill rig enters the ground at an angle of 5 - 30^{o}. Bentonite drilling mud is pumped into the system to operate the drill motor, act as a coolant, and wash the spoil to the surface. The drilling operation is monitored and steered remotely with a survey system which takes position readings periodically from the drill stem bent housing.

The pipe used in this method must be able to accommodate the tensile stresses resulting from being pulled through the bore hole. Typically steel pipe is used; however HDPE has been suggested (1).

Hampton Roads Sanitation District completed a 2160 ft raw water crossing of the Elizabeth River using the Directional Drilling technique. The 48-inch diameter steel pipe was welded, sandblasted and coated with epoxy paint on-site in 80-ft sections. (5)

E. *Compaction Methods (Impact/Percussion, Rotary, Push Rod)*

Compaction methods are often referred to as expansive installation techniques because the bore hole is created by displacing the soil rather than removing it. Consequently it is restricted to small diameter pipe and compressive soils.(1)

Pipe can be pulled into the opening directly behind the impact-type machine. This is done in noncohesive, granular soils where the bore hole may collapse.(6) Where the soils are firm, rigid pipe can be pushed through the opening. (1)

F. *Pipe Ramming (Impact Ramming)*

A percussion tool (typically powered by compressed air) drives the pipe with a hammering action. Alignment control is limited, and only steel pipe should be installed using this method. A water or bentonite slurry lubricant may be applied to the pipe exterior to reduce friction. (1)

Small pipe (< 8-inch) is installed with a closed, bullet-shaped leading end; soil is displaced as in the compaction methods. The larger pipes are driven with the pipe face open, and soil is removed from inside the pipe.(1)

G. *Water Jetting (Wet Boring)*

Pressurized water is directed through a probe to wash out the bore hole. Overcut cannot be controlled, and settlement due to overexcavation is probable. This method should not be permitted.

DESIGN CONSIDERATIONS

1. <u>Soils</u>

All significant projects should require soil test borings, soil classification, and groundwater levels. Prospective contractors should be encouraged to excavate test pits. (1)

Soils with high shrink-swell potential, such as some clays and shales, non-homogeneous soils (those with concretions or rock), and fractured rock with blocks or seams require special analysis of horizontal and vertical loads on pipe. (11)

2. <u>Alignment</u>

Trenchless construction methods which use remotely controlled steering and alignment sensors are better suited to gravity lines than methods which cannot achieve accurate line and grade. (2)

Boring methods may encounter problems maintaining alignment when the cutting face passes through rocky soils or soils/strata of varying densities. (3)

3. <u>Pipe Properties</u>

A. Rigidity

Rigid pipe includes reinforced concrete (RCP) and clay. The design is typically based on the pipe three-edge bearing strength, a bedding factor, and a safety factor.

Flexible pipe includes: steel, ductile iron (DIP), acrylonitrile-butadiene-styrene (ABS), polyvinyl chloride (PVC), polyethylene (PE), fiberglass-reinforced plastics (FRP), and reinforced plastic mortar (RPM). The design is usually based on the most common performance limitation - deflection. The common deflection limit for cement-mortar lined DIP is 3%, for PVC it is 5%. Limits may also be expressed as allowable stress, strain, crushing or buckling strength. (11)

B. Strength

The installation method imposes axial loading conditions on the pipe. Pipe which is pulled into the bore hole (horizontal earth boring) requires high tensile strength; pipe which is jacked into position (auger boring, microtunneling) requires good compressive strength. (1,10)

The earth load, live load, bedding factors and selection of design safety factors determine pipe strength required after installation.

1. The earth load on trenchless installations of pipe will generally be less than that for pipe installed by open trench at the same depth. This is due to the cohesive forces of the soil. (10, 11) Where the earth is subject to seasonal frost and cracking, cohesive forces should be taken as zero.(11)
2. Positive contact of the pipe and the surrounding earth provide an ideal bedding condition when the bore diameter is controlled. This is because flexural stresses on the pipe wall are nearly eliminated. If the boring is overexcavated, filling of the annular space with sand, grout, etc. will accomplish the same goal. Otherwise, a reduced bedding factor must be selected (rigid pipe design) or the cohesive factor eliminated (flexible pipe design), to account for the void spaces. (10,11)
3. Live loads on the pipe after installation are determined independent of the construction method.

B. Joint Design

Pipe joints must be designed for the installation method. Pipe which is jacked into place should have joints designed to transmit jacking forces from one pipe section to the next. The method and the joints must provide a uniform distribution of bearing forces around the pipe circumference. Protective joint spacers may be required to prevent damage to the joint and to ensure uniform bearing around the joint. Installation should follow recommendations of the pipe manufacturer. (8)

4. Casing & Carrier Pipe Installation

Where a carrier pipe is installed inside a casing or tunnel liner, flotation must be prevented. The annular space may be grouted or filled with sand, or the carrier pipe may be blocked. Hold-down jacks can also be used. (8) The annular space should be sealed at sewer connections to manholes, to prevent the entrance of animals, etc.

Carrier pipe should be installed with skids to protect the pipe and bell during the procedure. The skids also provide long term bearing support and prevent the pipe from resting on the bells. Skids may be spaced at intervals (based on pipe diameter) or extend from one joint to the next. The pipe is either pulled with a cable or it is jacked into the casing pipe.(9,10)

TABLE 1
HORIZONTAL EARTH BORING METHODS

* Typical

METHOD	PIPE DIAM (inch)	DRIVE SPAN* (feet)	CASING/CARRIER PIPE MATERIAL	SOIL	GROUND-WATER	REMOTE STEERING CONTROL	APPLICATIO N
Auger Boring	2 - 72	60 - 300	Steel, RCP	Clay, silt, sand, gravel, rock	OK	No	Casing pipe - pressure lines or short gravity spans
Slurry Rotary Drilling (Slurry Boring)	1 - 48	30 - 1000	Steel, RCP, PVC, DIP, FRP, corrugated metal		No	No	Casing or Carrier pipe - Pressure lines or short gravity spans
Microtunneling	6 - 36	80 - 400	RCP, DIP, Clay, Steel, FRP	Soft clay, sand (most)	OK	Yes	Carrier pipe - gravity or pressure (rare)
Horizontal Directional Drilling	4 - 54	1000 -4000	Steel (HDPE)		OK	Yes	Carrier pipe - pressure lines
Compaction Techniques	1 - 6	16 - 300+	Steel (pushed) Steel, PVC, PE (pulled)	Compressible Homogeneous	OK	Some	Carrier pipe -Pressure lines
Pipe Ramming (Impact Ramming)	2 - 80 4 -36*	≤ 500 20 -100*	Steel	Compressible Homogeneous	OK	No	Casing pipe for pressure lines
Water Jetting (Wet Boring)	1 - 4	16 - 32 (between access)			No	No	Carrier pipe -pressure lines

REFERENCES

1. Committee on Construction Equipment and Techniques, "Trenchless Excavation Construction Methods: Classification and Evaluation", Journal of Construction Engineering and Management, ASCE, Sep 1991, pp521-536.

2. Fedotoff, Roy C. et al, "Trenchless Techniques Improve Pipelines", Water Environment & Technology, April 1991, pp 48-52.

3. Derr, Henry R. & Jones, Bruce W., "Upgrading Dubai's Sewers", Civil Engineering, Aug 1994, pp 60-63.

4. Pilecki, Tad, Klein, Stephen J., & Hamid, Art, "Trenchless Relief", Civil Engineering, Jan 1994, pp 58-60.

5. Ensor, W. Douglas, et al, "Drilling with Direction", Civil Engineering, Sep 1993, pp 48-51.

6. TT Technologies Inc., 1771 Mallette Road, Aurora, ILL. 60505

7. WPCF MOP No. 9: Design of Sanitary and Storm Sewers, pp 270-273.

8. AWWA No. M9: Concrete Pressure Pipe, pp 70-73.

9. AWWA No. M23: PVC Pipe - Design and Installation, pp 65-66.

10. American Concrete Pipe Association, Concrete Pipe Design Manual, 1987, pp 27-54, 84-86.

11. ASCE No. 60, WPCF MOP No FD-5: Gravity Sewer Design and Construction, 1982.

12. "Boring Equipment Selection Charts", Pipeline & Utilities Construction, March 1995, pp 73-84.

Figures 2 - 5 taken from Reference 1.